Using the IR Cloud Emissivities in the MYD06 Collection 6 Data to Estimate Cirrus Cloud Optical Depth and Particle Size

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1. Introduction

Knowledge of cirrus cloud optical properties are critical in understanding its role in the earth climate and in developing better parameterization schemes for climate models. The official MODIS cloud products provide a global view of cloud optical depth and particle size with both high temporal and spatial resolutions. However, due to the use of shortwave channels in the bispectral method, data availabilities are limited to daytime. The recently released MODIS Collection 6 (C6) product includes cloud emissivities at infrared channels (8.5, 11, 12 and 13.3μm), making the estimation of cirrus optical properties at both day and night possible. In this study, cirrus optical depth and effective particle size are estimated using the Infrared cloud emissivities in the MYD06 C6 data. Retrievals are derived based on both a fixed ice crystal habit (Aggregate Column) and an empirical method, and the results are validated against CALIPSO-CALIPSO and MYD06 products. In addition, this new retrieval method is applied to MODIS C6 level 2 data from 2011 and meaningful statics are derived. The method presented here is similar as Garnier et al. (2013) but with better coverage when applied to MODIS product.

2. Data

- One month collocated MODIS and CALIPSO data by PEATE at University of Wisconsin, Madison
- Single scattering database for 9 severely roughed ice crystal habits at 396 wavelength and 189 particle sizes
- MODIS C6 MYD06 data for 2011

3. Physical basis and methods

- According to Parol et al. (1991), a critical β parameter, relating the emissivities at two wavelengths x and y, can be defined as follows:

$$\beta_{x,y} = \ln(1-e_{c,y}) \Big/ \ln(1-e_{c,x})$$

Furthermore, β can be calculated accurately using an approximate formula based solely on the single scattering properties

$$\beta_{x,y} = \left(Q_{e,y}(1-\omega_{o,y}g_y)\right) \Big/ \left(Q_{e,x}(1-\omega_{o,x}g_x)\right)$$

where Q_e is extinction efficiency, ω_o is single scattering albedo, and g is asymmetry factor. A nearly monotonic relationship can be derived between effective particle size and β from the single scattering database.

- Particle Size

Based on β computed from MODIS C6 IR emissivities and the pre-computed relationship, cirrus effective particle size can be estimated.

- Optical Thickness

The absorption optical depth is expressed as

$$\tau_{abs} = -\mu \ln(1-e_c)$$

where μ is cosine of satellite zenith angle, and the full optical thickness at the IR wavelength is

$$\tau_{ir} = \frac{\tau_{abs}}{(1-\omega_o g)}$$

Assuming extinction efficiency at visible wavelength is approximately 2, the visible optical depth is computed as

$$\tau_{vis} = \frac{2}{Q_e}\tau_{ir}$$

Fixed habit and Empirical method

In MODIS C6, aggregate column is adopted as the ice crystal habit. However, in deriving effective particle size (EPS), it is found that other habits often show better spectral consistency. Hence, an empirical retrieval curve for each β is derived based on 1-month MODIS-CALIPSO collocation data as follows: first an optimal EPS is selected based on minimized spectral inconsistency from the 9 habits, and then all optimal EPS are grouped together to obtain a mean value for each bin size. A final EPS is the mean of values derived from the two empirical curves.

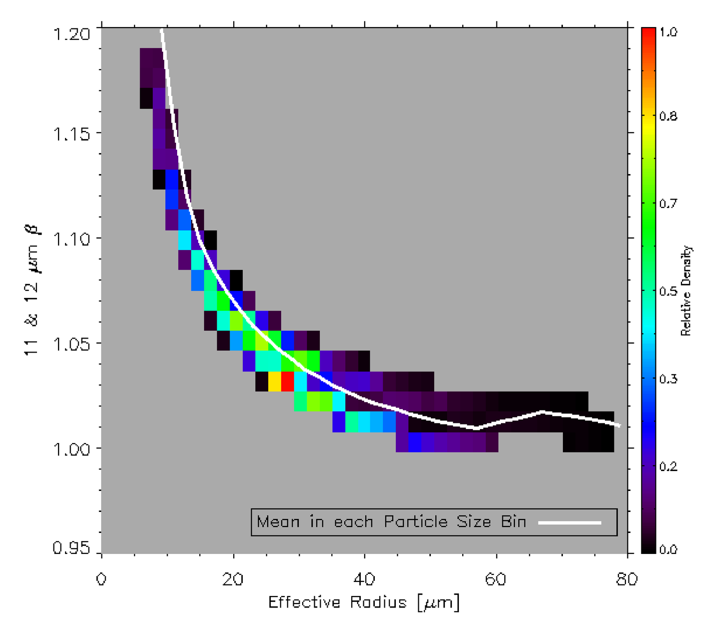

Fig.1 Empirical relationship between $\beta_{11,12}$ and effective radius. A smoothing is applied to get the empirical curve (white line). Color scale indicates density of points based on optimal selection of EPS.

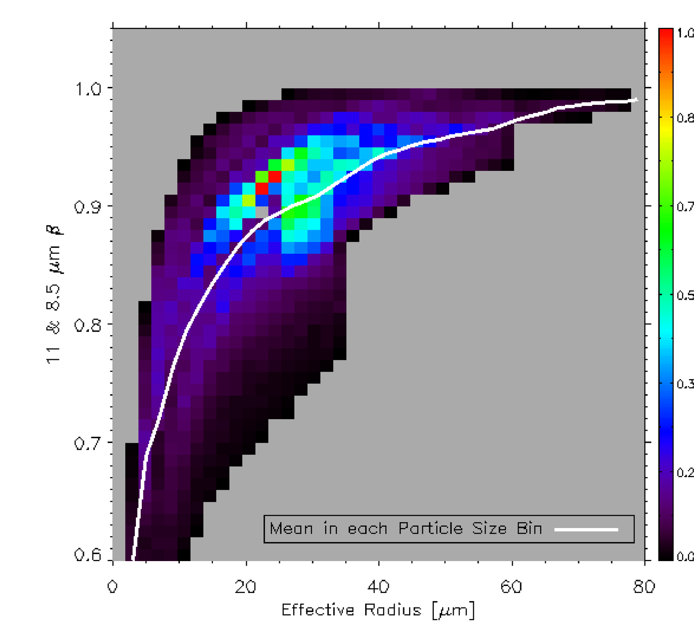

Fig.2 Same as Fig. 1 but for $\beta_{11,8.5}$

4. Validation

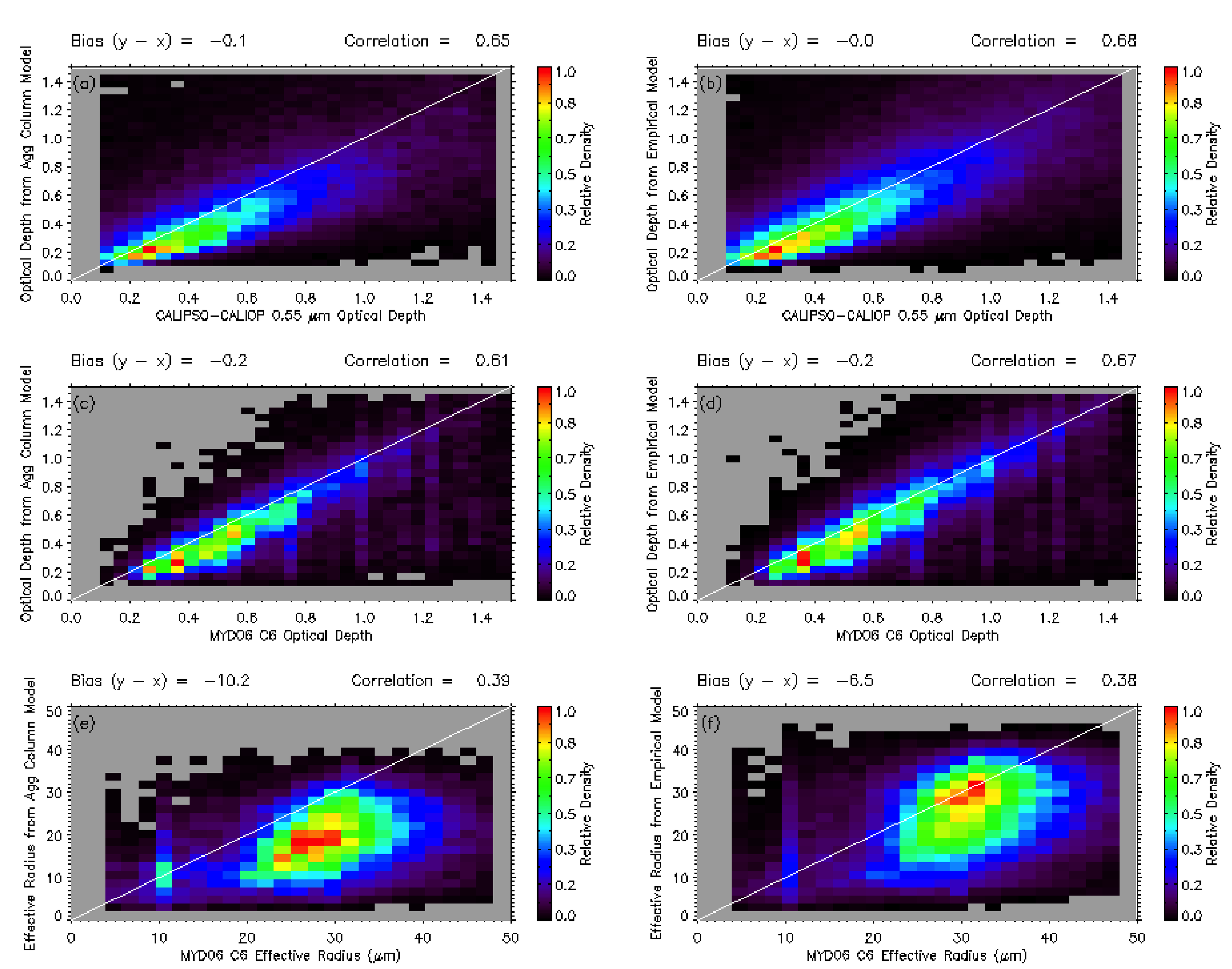

Fig.3 Comparison of IR retrieved optical depth against CALIPSO-CALIPSO (a-b), MYD06 C6 (c-d), and IR retrieved EPS against MYD06 C6 (e-f). Left column is based on Aggregate Column habit, and right column is from empirical method.

5. Results

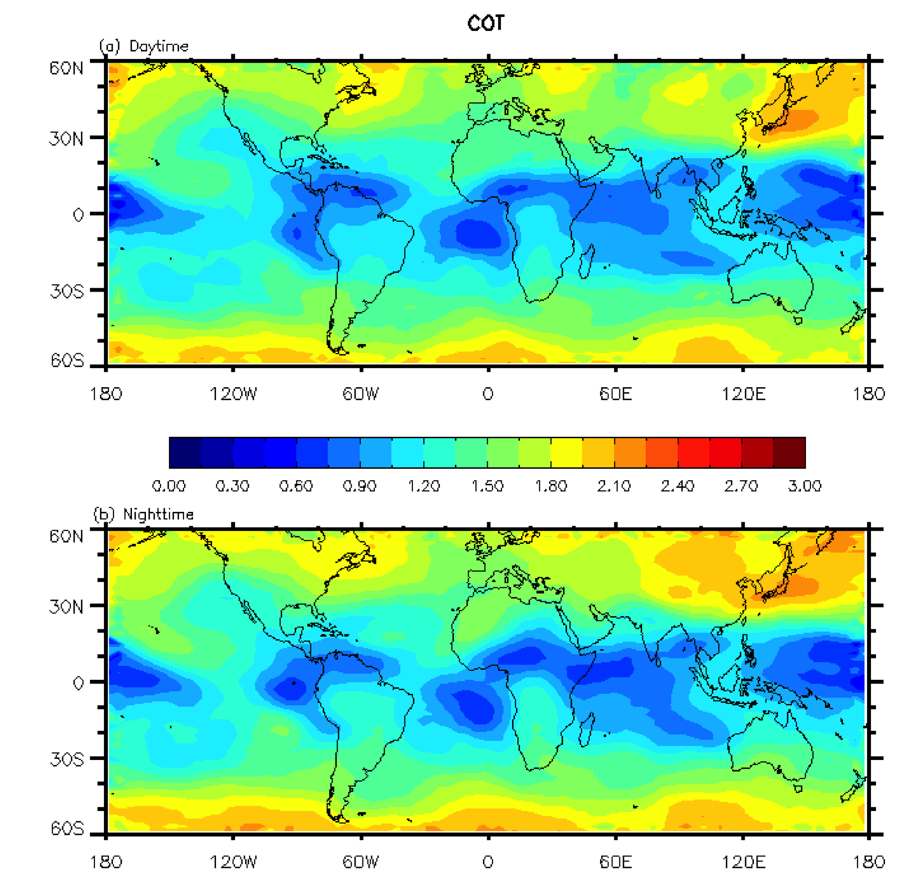

Fig.4 Geographical distribution of 1-month mean cirrus optical depth in January 2011 for (a) daytime and (b) nighttime. Cirrus is defined as cloud top pressure < 440hPa, emissivity at 11μm < 0.95, and ice phase in MYD06. Spatial resolution is 4° longitude by 2° latitude. Smoothing has been applied to emphasize large scale structures.

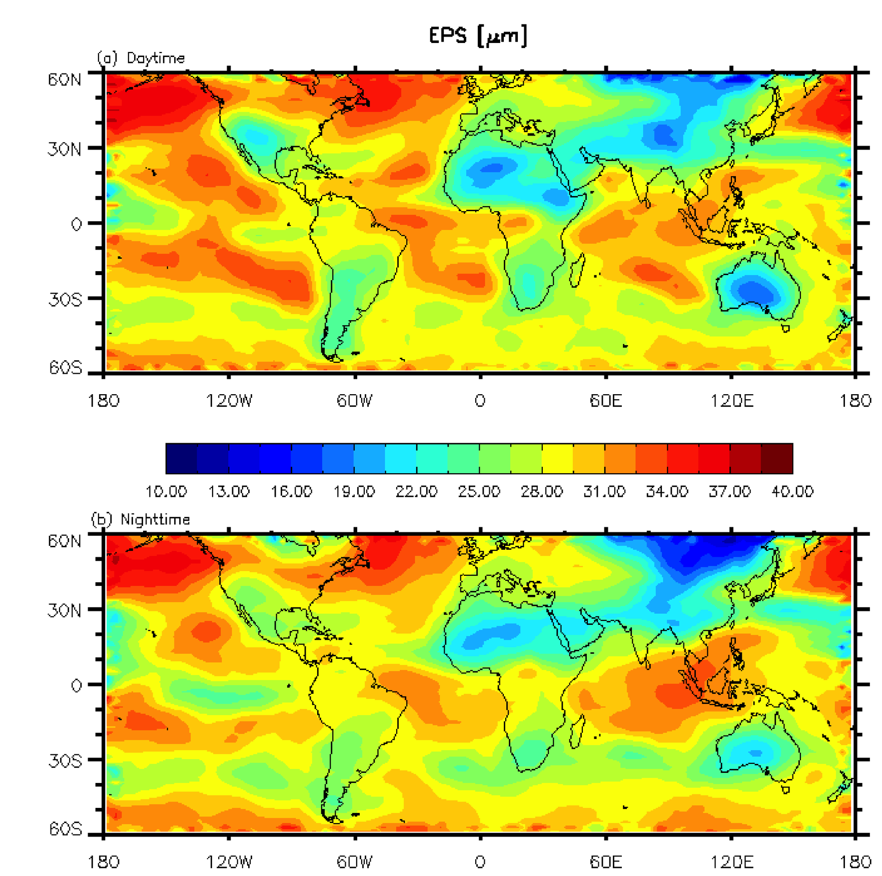

Fig.5 Same as Fig. 4 except for EPS

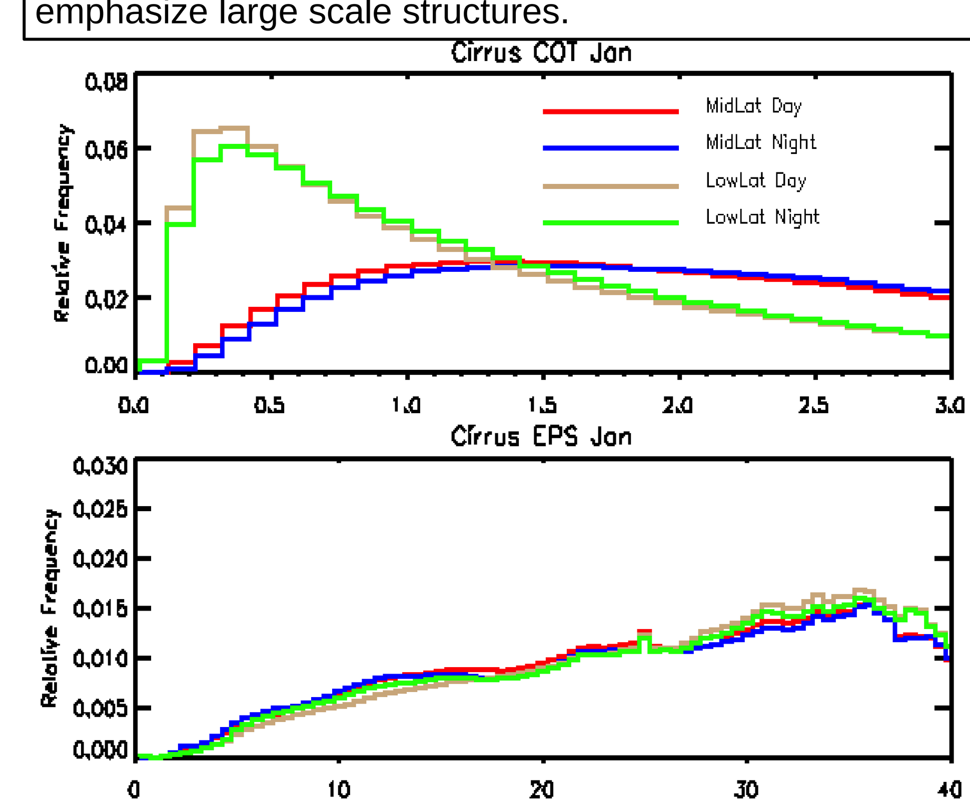

Fig.6 Histogram distribution of 5-day optical depth (upper) and EPS (bottom) in January 2011. Low latitude includes 30° N to 30° S, and Midlatitude means 30° -60° in each hemisphere.

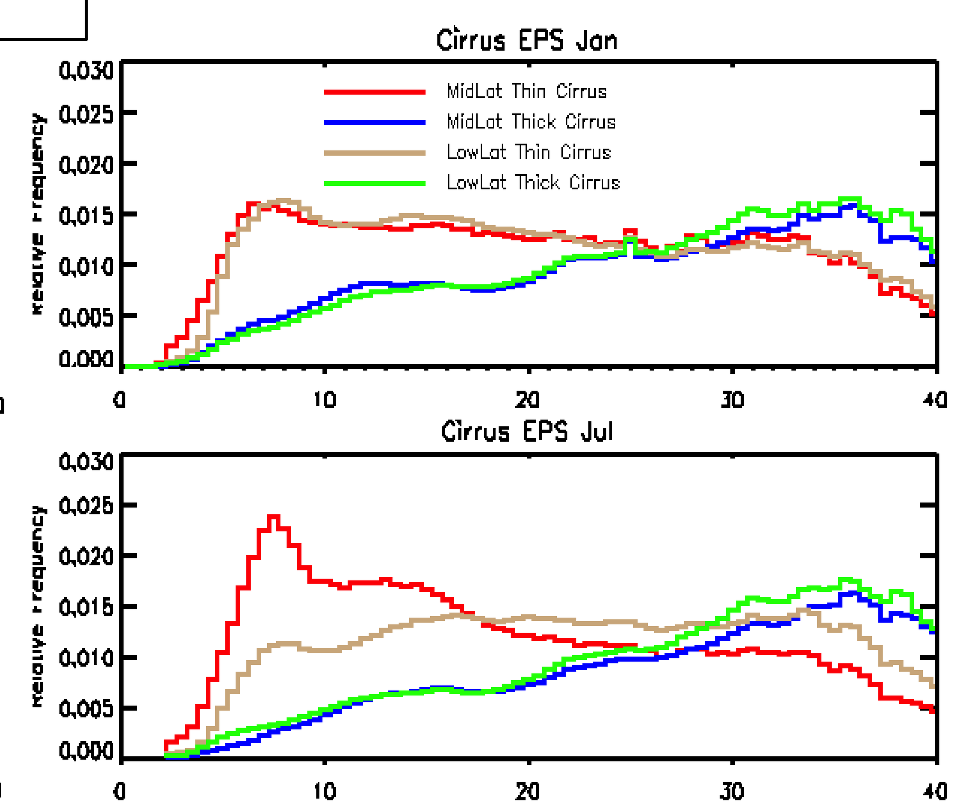

Fig. 7 Histogram distribution of 5-day nighttime cirrus EPS grouped based on latitudes and optical depth for January (upper) and July (bottom). Here thin cirrus indicates COT less than 0.3, and thick cirrus means COT between 0.3 and 3.

6. Summary

- A new method to retrieve cirrus cloud optical depth and effective particle size at both day and night from MODIS C6 MYD06 dataset is developed
- Optical depth retrievals using both aggregate column model and the empirical method agree well with the MODIS C6 and CALIPSO validation dataset, whereas effective particle size based on the empirical method shows better performance.
- Day and night differences are not pronounced
- Cirrus effective particle size is generally larger over ocean than over land
- Low latitudes are dominated by thin cirrus, whereas thicker cirrus are prevalent in midlatitudes
- Despite dominance by cirrus with different optical depth, the patterns of particle size are similar between midlatitude and tropics
- Further separation of particle size based on optical depth indicates that very thin cirrus shows a peak at less than 10μm, whereas thicker cirrus are dominated by larger particles
- Climatological study using more data are ongoing

References

Garnier, A., and Coauthors, 2013: Retrieval of Cloud Properties Using CALIPSO Imaging Infrared Radiometer. Part II: Effective Diameter and Ice Water Path. *J. Appl. Meteor. Climatol.*, **52**, 2582–2599.

Parol, F., J. C. Buriez, G. Brogniez, Y. Fouquart , 1991: Information Content of AVHRR Channels 4 and 5 with Respect to the Effective Radius of Cirrus Cloud Particles. J. Appl. Meteor., 30, 973–984.